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RVD 2.0-A Relief Valve Discharge Screening Model User's Guide

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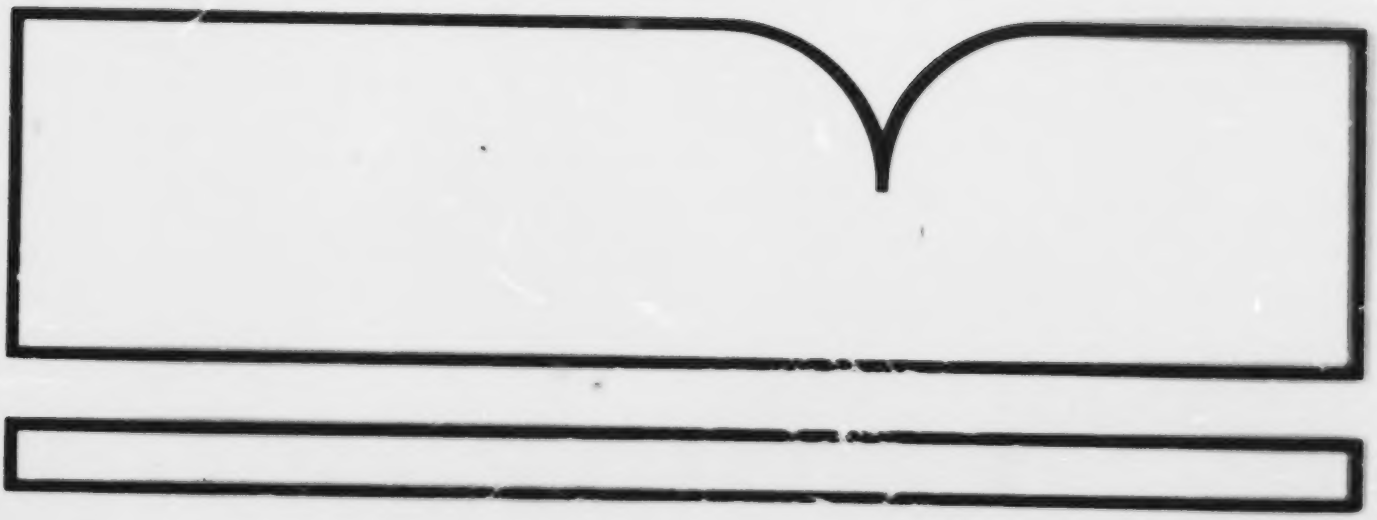

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USER'S GUIDE FOR RVD 2.0 — A RELIEF VALVE DISCHARGE SCREENING MODEL

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16. ABSTRACT

This document is the user's guide for RVD 2.0, a personal computer model which provides estimates of short-term ambient concentrations for screening pollution sources which emit denser-than-air gases through vertical releases. The code is based on empirical equations derived from wind tunnel tests. The user's guide describes the bases, features, applicability and limitations of the model, and provides two example runs of the model for illustrative purposes and benchmark testing.

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User's Guide for RVD 2.0 — A Relief Valve Discharge Screening Model

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Office of Air Quality Planning and Standards
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PREFACE

The RVD (Relief Valve Discharge) model is an IBM-compatible PC model which provides short-term ambient concentration estimates for screening pollutant sources emitting denser-than-air gases through vertical releases. The model is based on empirical equations derived from wind tunnel tests performed by Hoot, Meroney, and Peterka (1973).

This document describes the bases, features, applicability, and limitations of the RVD 2.0 model. Input data needed to utilize the program are identified, and example runs of the model in batch and interactive mode are provided to illustrate model application.

It is likely that the RVD program will undergo changes based on experience gained with applying the model. Comments on the model or the user's guide should be addressed to Dr. David Guinnup, Source Receptor Analysis Branch (MD-14), U.S. EPA, Research Triangle Park, NC 27711.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Definition
c	Ambient Concentration at Receptor (ug/m^3)
c_f	Final Concentration at Desired Averaging Time (ug/m^3)
c_1	1-Hour Steady-State Concentration (ug/m^3)
c_t	Ambient Concentration at Plume Touchdown (ug/m^3)
c_{ta}	Concentration at Specifed Averaging Time (ug/m^3)
d	Stack Diameter (m)
D_h	Plume Dilution Ratio at Maximum Plume Rise
f	Volume Fraction Liquid in Release
Fr	Froude Number (vertical densimetric)
Fr_H	Froude Number (horizontal densimetric)
g	Acceleration of Gravity (m/sec^2)
h_s	Stack Height (m)
Δh	Maximum Plume Rise Height Above Stack (m)
M_c	Molecular Weight of Contaminant or Pollutant
M_e	Equivalent Molecular Weight
M_s	Molecular Weight of Exhaust Gas
M_h	Equivalent Molecular Weight of Plume at Maximum Plume Rise
p	Wind Speed Profile Exponent
Q	Exhaust Gas Mass Flow Rate (kg/sec)
Q_c	Pollutant Emission Rate (kg/sec)

Ri_o	Release Richardson Number
R_v	Velocity Ratio
SG	Specific Gravity
t_a	Averaging Time (seconds)
t_d	Release Duration (seconds)
T_a	Ambient Temperature (K)
T_s	Stack Exit Temperature (K)
T_h	Temperature at Maximum Plume Rise (K)
u	Wind Speed at Stack Height (m/sec)
u_{10}	Wind Speed at 10 meters (m/sec)
u_*	Friction Velocity (m/sec)
v_s	Exit Velocity (m/sec)
x	Downwind Distance of Receptor (m)
x_c	Downwind Distance of an Ambient Concentration of 5000 ppm (m)
x_t	Downwind Distance of Plume Touchdown (m)
x_h	Downwind Distance of Maximum Plume Rise (m)
δ	Fractional Density Ratio at Maximum Plume Rise
ρ_a	Ambient Air Density (kg/m^3)
ρ_o	Exhaust Gas Density (kg/m^3)
ρ_L	Liquid Density (kg/m^3)
ρ_v	Vapor Density (kg/m^3)
$\Delta\rho_h$	Density Difference at Maximum Plume Rise (kg/m^3)

1 INTRODUCTION

Recently, there has been an increased interest in the short-term impact of toxic air pollutants. Sources of these pollutants include denser-than-air releases (e.g., emissions from pressure relief valves). Conventional dispersion modeling techniques may not be able to provide a reasonable estimate of ambient concentrations resulting from such releases. Several complex dense-gas release and dispersion models have been developed and are currently being further refined with support from the EPA and others. The use of one of these models to simulate every potential dense gas release scenario is generally impractical. For many cases, it is desirable to "screen" a particular dense gas scenario for potential dense gas effects with a simplified model prior to expending the time and effort involved in performing a rigorous simulation.

The RVD (Relief Valve Discharge) model has been designed as a simplified screening technique which is applicable to elevated releases of denser-than-air gases. The model will estimate the plume centerline ground-level ambient concentration at plume touchdown (which corresponds to the maximum ground-level concentration) and ground-level concentrations for up to 30 downwind centerline receptor locations. Even though the name of the model would imply that it is only applicable to pressure

relief valves, this is not the case. In fact, any vertically-directed gas release which may potentially exhibit denser-than-air behavior can be modeled using this technique.

The RVD technique is derived empirically from wind tunnel tests performed by Hoot, Meroney, and Peterka[1] simulating negatively buoyant plumes from vertically-directed point sources. One characteristic of such an empirical approach is that it may not provide reliable concentration estimates for atmospheric conditions other than those under which the experimental data were obtained. Since the wind tunnel experiments upon which a portion of the model is based are typically characterized by either quiescent conditions or a laminar windflow, model simulation results most closely represent those which might be encountered under stable atmospheric conditions (E or F stability class). As a result, concentration predictions for unstable or neutral atmospheric conditions (where atmospheric turbulence may play a large role in the dilution of a plume) may be overestimated.

In versions of this model prior to RVD 2.0, the model multiplied concentration estimates by a factor of 5 prior to printing them out. This procedure was intended to assure conservatism of the results. Currently, the model contains no multiplicative factor, and is therefore an unbiased

representation of the experimental results from the original work of Hoot, et al. A comparison of these results to those which might be obtained under actual atmospheric conditions has never been realized. To insure that the concentration estimates from RVD meet the intent for conservatism implicit in a screening technique, the concentration estimates should be multiplied by a factor of 2.0 prior to comparing them with significance levels or health effects thresholds. Given this degree of conservatism, it is unlikely that the model will underestimate the impact of a particular release scenario. In this way, a release with a potentially dangerous impact can be readily identified as the subject for more sophisticated modeling efforts.

The major differences between this version of RVD (2.0) and previous versions are associated with the input and output procedures. Now the capability of storing keyboard-entered data on a disk file for future use and the ability to incorporate such stored data directly into an RVD run are included.

A general limitation of the RVD model is that it assumes no secondary source cloud. That is, RVD would not be applicable to the evaporation of a pollutant from a liquid spill. In addition, the plume is assumed to be in a single gaseous phase. Thus, no liquid entrainment from the release or particle deposition from the plume is considered. Note however, it is possible that the

model can be used to simulate aerosol dispersion (see Section 3.3) by providing as input the "equivalent" molecular weight of the aerosol mixture for the exhaust gas molecular weight, but the accuracy of such a simulation has not been evaluated. Users are advised that, in such an application, the velocity check calculation (described in Section 3.5.1) is not valid and the printed warning should be ignored.

The RVD model does not attempt to calculate building wake effects or perform concentration calculations in building cavity regions. In addition, it does not carry out complex terrain calculations or crosswind concentration calculations, and its results are independent of surface roughness.

The purpose of the remainder of this document is to familiarize the user with details concerning the features, applicability, and limitations of RVD and to provide step-by-step instructions for its use on an IBM-compatible PC.

2 TECHNICAL DESCRIPTION

The RVD model provides short-term ambient concentration estimates resulting from vertical dense gas releases. This section summarizes the technical aspects of the model. If more detail is needed, the papers cited below should be consulted.[1,2]

Hoot, T.G., R.N. Meroney, and J.A. Peterka ,1973: Wind Tunnel Tests of Negatively Buoyant Plumes, EPA-650/3-74-003, US Environmental Protection Agency, Research Triangle Park, NC 27711.

Puttock, J.S., D.R. Blackmore, and G.W. Colenbrander, 1982: "Field Experiments on Dense Gas Dispersion,"in Dense Gas Dispersion (R.E. Britter and R.F. Griffiths, ed.), Elsevier Scientific Publishing Comp., New York.

2.1 Determination of Model Applicability

The RVD model is only applicable when the combined physical properties of the release and the atmosphere (e.g., the molecular weight, emission rate, temperature, wind speed) result in the emission of a denser-than-air plume. Since it is not always a straightforward task to ascertain whether or not a denser-than-air plume will result from a given hypothetical scenario, the model performs this assessment for the user. To determine whether a particular release results in a denser-than-air plume, two successive tests are performed by the program. The first test checks for the dominance of dense gas effects at the point of release to the atmosphere, while the second test checks for the importance of dense gas effects at the point of maximum plume

rise (i.e., the top of the plume).

In the first test, the release Richardson number, Ri_o, is calculated using equation (1). The value is calculated for each atmospheric stability class and wind speed combination being considered in the analysis.

$$Ri_o = [g\ (\rho_o/\rho_a - 1)\ Q]/[u\ d\ \rho_a\ u_{10}^2\ (u_*/u_{10})^2] \qquad (1)$$

where g is the acceleration of gravity (= 9.8 m/sec^2), ρ_o is the plume density (kg/m^3), ρ_a is the ambient density (kg/m^3), Q is the exhaust gas mass flow rate (kg/sec), u is the wind velocity at the top of the stack (m/sec), d is the stack diameter (m), u_{10} is the wind velocity at 10m above the ground, and u_*/u_{10} is the ratio of friction velocity (m/sec) to the wind speed at 10m (m/sec). In this version of RVD, this ratio is assumed to equal 0.06 for all atmospheric stability classes. The value of u is calculated via the equation:

$$u = u_{10}(h_s/10)^p \qquad (2)$$

where h_s is the stack height (m) and p is the wind speed profile exponent, which varies as a function of atmospheric stability (see Section 3.2).

If the value of Ri_o for a particular wind speed/stability combination is greater than 30, then the plume is considered to behave as a dense gas at the release point under those conditions[3], and the program continues to the next test. If the value is less than or equal to 30, then the plume is considered to be non-dense under those conditions, and no further calculations are made. Conventional dispersion models for neutrally-buoyant plumes are applicable for such cases.

Once the first test is passed by a particular release scenario, the second test is performed to assess the importance of atmospheric dilution of the plume resulting from jet entrainment effects during the rise of the plume to its maximum height. In this test, the fractional density ratio, δ, (i.e., the ratio of the difference between the plume and ambient air density to the density of the ambient air) is calculated at the top of the plume. First, the height of the plume at maximum plume rise is calculated as the minimum of that which would occur in either a laminar wind or a windless (quiescent) atmosphere. In a laminar wind, the height from to the top of the stack to the middle of the plume at its point of maximum rise, Δh, is:

$$\Delta h = 1.32\ R_v^{1/3}\ SG^{1/3}\ Fr^{2/3}\ d \qquad (3)$$

where R_v is the ratio of the release velocity to the wind velocity at stack height, SG is the specific gravity of the exiting plume, and Fr is the vertical densimetric Froude number, defined by:

$$Fr = v_s / [gd(1 - \rho_a/\rho_s)]^{1/2} \qquad (4)$$

In a quiescent atmosphere, Δh is:

$$\Delta h = 2.96\ Fr\ d \qquad (5)$$

The lesser of the two calculated values of Δh is used to estimate the plume dilution ratio at maximum plume rise, D_h, via the following equation:

$$D_h = 5.67 \times 10^{-2}\ (ud^2/Q)\ (\Delta h/d)^{1.85}\ (M_a/T_a) \qquad (6)$$

where M_a is the molecular weight of the exhaust gas and T_a is the ambient temperature. The equivalent molecular weight of the plume at the maximum plume rise, M_h, and the temperature at that point, T_h, are then calculated using mass and energy conservation equations:

$$M_h = [M_s + 28.96(D_h - 1)] / D_h \quad (7)$$

$$T_h = T_a - (M_s/M_h)(T_a - T_s) / D_h \quad (8)$$

where T_s is the stack exit temperature (°K). The fractional density ratio at maximum plume rise, δ, is finally calculated as:

$$\delta = [(M_h/28.96)(T_a/T_h)] - 1 \quad (9)$$

If this calculated fractional density ratio is greater than 0.005, then dense gas behavior is considered to dominate subsequent plume transport and the model proceeds to calculate plume touchdown and ground level concentrations. If the value is less than or equal to 0.005, the plume is considered not to behave as a dense gas and the user should consider a dispersion model for neutrally-buoyant plumes as more appropriate.

2.2 Concentration Estimates at Plume Touchdown

Assuming the previously-described tests indicate a denser-than-air release, the ambient concentration at plume touchdown (which also corresponds to the maximum ground-level concentration), c_c, is calculated via the following equation:

$$c_t = 6.0 \times 10^9 \, (Q_e/u) \, [(2\Delta h + h_s)/]^{-2.0} \qquad (10)$$

where Q_e is the pollutant emission rate (kg/sec) and h_s is the stack height (m).

RVD versions prior to 2.0 included a multiplicative "safety" factor of 5 which was used to adjust the ambient concentration predictions to insure conservative results (i.e., to guarantee that output concentrations were not underestimated). This safety factor does not appear in version 2.0, and thus the model predictions are now consistent with the original Hoot, et al., correlations. As such, the model predictions should be most accurate for release scenarios similar to the original wind tunnel experimental conditions, that is, under stable atmospheric conditions with low wind speeds and relatively low surface roughness. Due to the relatively small database available for evaluation of this model's performance, however, current guidance requires that when using this model in a regulatory situation as a screening tool, output concentrations should be multiplied (by the user) by a factor of 2 to avoid underestimation, especially when simulating very stable atmospheric conditions and short (one hour or less) averaging times. As further model development and evaluation continue, this guidance will be updated.

In addition to providing estimates of ambient concentrations at plume touchdown, the model also estimates the downwind distance from the source where touchdown occurs. This distance (as shown in equations (11) and (12)) is dependent upon the maximum plume rise, the ratio of release velocity to wind velocity, stack height and diameter, and the vertical and horizontal densimetric Froude numbers, Fr and Fr_H, respectively:

$$x_t = (d\ Fr^2/R_v) + 0.56\ (d\ Fr_H/R_v^{1/2})\ C_1 \qquad (11)$$

where $$C_1 = \{(\Delta h/d)^3\ [(2 + h_s/\Delta h)^3 - 1]\}^{1/2} \qquad (12)$$

and Fr_H is defined by:

$$Fr_H = u/[gd(\rho_a/\rho_o - 1)]^{1/2} \qquad (13)$$

The distance to plume touchdown is used in estimating ground level concentrations at further downwind distances as described in the next section.

2.3 Concentration Estimates at Downwind Distances after Touchdown

In addition to observing the trajectory behavior of vertical dense gas releases, Hoot, Meroney, and Peterka[1] studied the dense

gas plume after touchdown. Upon touchdown, the dense gas plume underwent a lateral spreading with crosswind concentration profiles remaining rather flat (the so-called "top hat" concentration profile). The subsequent downwind decay of centerline ambient concentrations at ground level was observed to follow a power law function with an exponent of -0.65. As the plume approached ambient density, the exponent shifted to -1.7. This shift, which corresponds to a shift in the dominance of dense gas effects on dispersion to the dominance of atmospheric turbulence, was observed to occur at an ambient concentration of about 5000 ppm.

The RVD model uses these observations to estimate ground-level centerline concentrations at different downwind distances after plume touchdown. Concentrations within the "dense gas effects dominated" region are calculated by the equation:

$$c = c_t \, (x/x_t)^{-0.65} \qquad (14)$$

where c is the ambient concentration at some user-specified receptor distance x (m). The distance to the point of transition, x_t, from the "dense gas effects dominated" regime to the "passive dispersion dominated" regime is calculated with equation (14) by substituting the 5000 ppm concentration for c and solving for x.

The calculation of concentrations at downwind distances beyond x_c is then made using the following equation:

$$C = C_t \ (x_c/x_t)^{-0.65} \ (x/x_c)^{-1.7} \qquad (15)$$

If a user-specified receptor distance is less than the downwind distance to plume touchdown, no concentration will be detected at that receptor site, and thus no concentration calculation is made at that receptor.

2.4 Concentration Estimates at Specific Averaging Times:

The concentration estimates provided by the correlations of Hoot, et al.[1], are considered steady-state or "point" concentrations. Thus, no time-averaging concentration modifications due to wind meander or atmospheric stability fluctuations are reflected in the equations. Since the RVD model is designed as a "screening" model, no specific attempt has been made to alter the equations in the model to account for such atmospheric fluctuations, and the steady-state concentration estimates are considered to be equivalent to 1-hour concentration averages. Indeed, since the transport of a significantly denser-than-air plume may be affected very little by wind meander, the interpretation of RVD point concentration results as 1-hour

averages may be quite realistic.

The RVD model does make concentration adjustments for two time-oriented factors. The first is a concentration reduction for releases whose duration is less than the averaging time of concern. The second is a peak-to-mean correction factor for averaging times less than 60 minutes. These two independent adjustments are described in the next two paragraphs.

If the release duration is less than the averaging time of interest to the user, the RVD model calculates a concentration reduction based on the ratio of the duration time to the averaging time:

$$c_c = c_i \ (t_d/t_a) \qquad (16)$$

where t_d is the duration of the release (min), t_a is the averaging time (min), c_c is the corrected concentration, and c_i is the initial steady-state concentration (which was calculated via equations (10), (14), or (15). If the release duration is greater than the averaging time, no concentration reduction is calculated.

In addition, if the averaging time of interest to the user is less than 60 minutes, a correction factor is calculated within the program using the following equation:

$$C_{t_a} = C_1 \ (60/t_a)^{0.2} \qquad (17)$$

where C_{t_a} is the concentration for the desired averaging time. To insure conservatism in the absence of experimental data on the subject, no correction factor is calculated for averaging times greater than 60 minutes.

For screening analyses, all concentrations should be multiplied by a factor of 2 after being printed out by the program.

3 MODEL IMPLEMENTATION

3.1 Summary:

The RVD model has been designed for ease of use. It is written in BASIC programing language and can be run on any IBM-compatible PC with a BASIC interpreter capability. The model can be run either interactively or in batch mode. Appendix A contains a copy of the program code.

To access the program from a hard disk, copy RVD to the hard disk ("copy a:rvd.* c:"). After the program has been copied, then type in the command "rvd" at the DOS prompt. This will begin the interactive session as discussed later (see example 3.4a).

If RVD is to be run from a floppy diskette, invoke the BASIC interpreter and type in the BASIC command "load A:RVD.bas". This will load the program into the current memory. To begin the program, type in the command "run".

In section 3.4, two example model runs are presented. One describes the interactive process and the other describes running RVD in the batch mode. The source modeled in example 3.4.1 is a pressurized release from a plugged line. In this example, phosgene was emitted for 10 minutes at a rate of 6.26 kg/sec. The source modeled in example 3.4.1 is a release from a pressure

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relief valve where vinyl chloride was emitted for 3 minutes at 15.12 kg/sec.

3.2 Input Data Description:

The RVD model requires input data on the emission source to be modeled, meteorological conditions, and receptor locations. These data can be entered through a data file (batch mode) or by answering the questions prompted by the computer (interactive mode). Both are described in the examples presented in section 3.4. Batch mode is accomplished using an input data file of ASCII characters. The data are input in free format, allowing for separation via spaces, commas, or semi-colons. The creation of a data file can be most easily accomplished by executing RVD in the interactive mode and responding affirmatively to the question regarding storage of the input data to a file. Subsequent runs with similar scenarios may be easily performed by making editorial changes to the data file (with available wordprocessing software) and executing RVD in batch mode.

Below is a summary of the input data necessary to run RVD.

Pollutant Emission Rate (kg/sec): This is the mass emission rate at the source exit point of the pollutant for which the ambient concentrations are to be estimated.

Exit Velocity (m/sec): The average linear velocity of the total plume exiting the source.

Stack Diameter (m): The exit diameter of the point source.

Exit Temperature (K): The temperature of the plume exiting the source.

Stack Height (m): The height above ground level of the elevated point source.

Pollutant Concentration (volume %): The initial concentration of the pollutant in the plume (determined from a pollutant mass balance, process calculation, or stack measurement).

Exhaust Gas Molecular Weight: The average molecular weight of the entire exiting plume.

Exhaust Gas Mass Flow Rate (kg/sec): Rate of total mass flow from the source at the exit point.

Pollutant Molecular Weight: The molecular weight of the pollutant for which ambient concentrations are to be estimated.

Release Duration (sec): The time elapsed from beginning to end of the emission.

Averaging Time (sec): The time period over which the concentration estimates are averaged.

Release Pressure (atm): The absolute pressure just inside the vessel or pipe acting as the source of the emission. This is used to perform a check on the user-specified velocity. If the emission is routed from a pressurized vessel through a stack to the atmosphere, this pressure should be equal to 1 atm. If the pressurized source emits directly to the atmosphere, this pressure should be equal to the actual vessel pressure.

Number of Wind Speeds: The number of wind speeds (maximum number is 21) the user desires to investigate.

Wind Speed (m/sec): The actual wind speeds being considered in the analysis. These values must be equal to 1.0 m/sec or greater.

Number of Receptors: The number of downwind distances (maximum is 30) the model will read into the program.

Receptor Distances (m): The downwind distances at which the user desires ambient concentration estimates.

Ambient Temperature (K): Ambient temperatures are to be input for all six stability classes (A through F). The default values are 298 K for all stabilities.

Wind Speed Profile Exponents: The wind speed profile exponents are fixed according to the user specification of "rural" or "urban". These are consistent with those used in the EPA's UNAMAP series models (for example, see reference 5).

An example listing of an input data file is shown on the right-hand side of Figure 3.1, with variable descriptors on the left. This file was generated by the example run depicted in Section 3.5.1 (referred to by the filename "a:phos.dat").

DESCRIPTORS	INPUT FILE
Title	Phosgene Release
Pollutant Emission Rate (kg/sec)	6.26
Exit Velocity (m/sec)	22
Stack Diameter (m)	.3
Exit Temperature (K)	293
Stack Height (m)	24
Pollutant Concentration (volume %)	100
Exhaust Gas Molecular Weight	99
Exhaust Gas Mass Flow Rate (kg/sec)	6.26
Pollutant Molecular Weight	99
Release Duration (min)	10
Averaging Time (min)	15
Release Pressure (atm)	1.01
Number of Wind Speeds	5
Wind Speeds (m/sec)	1 1.5 2 2.5 3
Number of Receptors	2
Receptor Distances (m)	120 210
Ambient Temperatures (K)	298 298 298 298 298 298
Urban(0) or Rural(1)	0

Figure 3.1: Input Data File

3.3 Notes on the Simulation of Aerosol Releases

While the extrapolation of the RVD approach to the simulation of aerosol cloud dispersion has not been explicitly evaluated, it has been suggested that the model's utility may extend into this area. Accordingly, appropriate simulation of such a release requires a slightly modified approach from that generally described in this guide. The excess density of the released cloud owing to the presence of liquid droplets may be simulated by entering an "equivalent molecular weight", or M_e, for the exhaust gas molecular weight, M_o. This can be calculated if the volume fraction of liquid in the release, f, is known:

$$\rho_o = [\, f\rho_L + (1 - f)\rho_v] \qquad (17)$$

$$M_e = (\rho_o/\rho_v)\ M_c \qquad (18)$$

Here, ρ_L is the density of the liquid at vessel conditions (kg/m^3), and ρ_v is the density of the vapor (kg/m^3) at release temperature and atmospheric pressure. All other input parameters remain unchanged.

Since the flowrate of contaminant and of total exhaust gas will be equal in this type of simulation, and since the user has entered an "equivalent" molecular weight, a consistency check

routine (described in Section 3.5) in the interactive input processor will be violated. The way to get around this problem is to:

(1) Enter source and meteorological data using the interactive mode of RVD, but enter the same molecular weight for the exhaust gas as that of the contaminant gas;

(2) Scroll the results to the screen (ignoring them), and save the input parameters on a disk file;

(3) Edit the disk file (using any convenient ASCII editing capability), changing the exhaust gas molecular weight to the equivalent molecular weight of the aerosol, and;

(4) Rerun the program using the edited disk file.

In this way, the consistency check is circumvented, and the parameters appearing in the data file will be those directly used in the calculations.

3.4 Model Output:

After the calculations have been performed by the model, the results can be printed either on the terminal screen or the printer depending on the specification of the user. Results can be previewed at the screen prior to being sent to the printer, and this is the recommended mode of operation.

The results are presented in five separate tables. The first table presents the input data used in the model run. The second table provides a quick summary of wind speed and atmospheric stability class combinations which result in dense gas behavior. The release Richardson numbers calculated in the first dense gas test are presented in the third table. The ground level concentrations estimated by RVD are presented in the last two tables. The plume touchdown distance and concentration and the maximum plume rise are presented with each meteorological condition in the fourth table and the ground level concentration for each receptor location is provided in the last table. If the receptor is located at a downwind distance shorter than the plume touchdown, the model does not calculate a concentration at that receptor.

3.5 Example Model Runs:

3.5.1 Interactive Mode

This example illustrates using the RVD model in the interactive mode. The source being modeled is a pressurized release of phosgene from a plugged gas line. The source emits 6.26 kg/sec of phosgene over a 10 minute period. The source is 24 meters high, 0.3 meters in diameter, and the line pressure is 1.01 atm, causing the exhaust gas to exit at a velocity of 22

m/sec. The exit stream is modeled as 100% phosgene at 293 K.

Five wind speeds are examined ranging from 1.0 to 3.0 m/sec. The ambient temperature is assumed to be 298 K for all stability classes and the 15-minute ground level concentrations are to be estimated at two specified downwind distances, 120 and 210 meters.

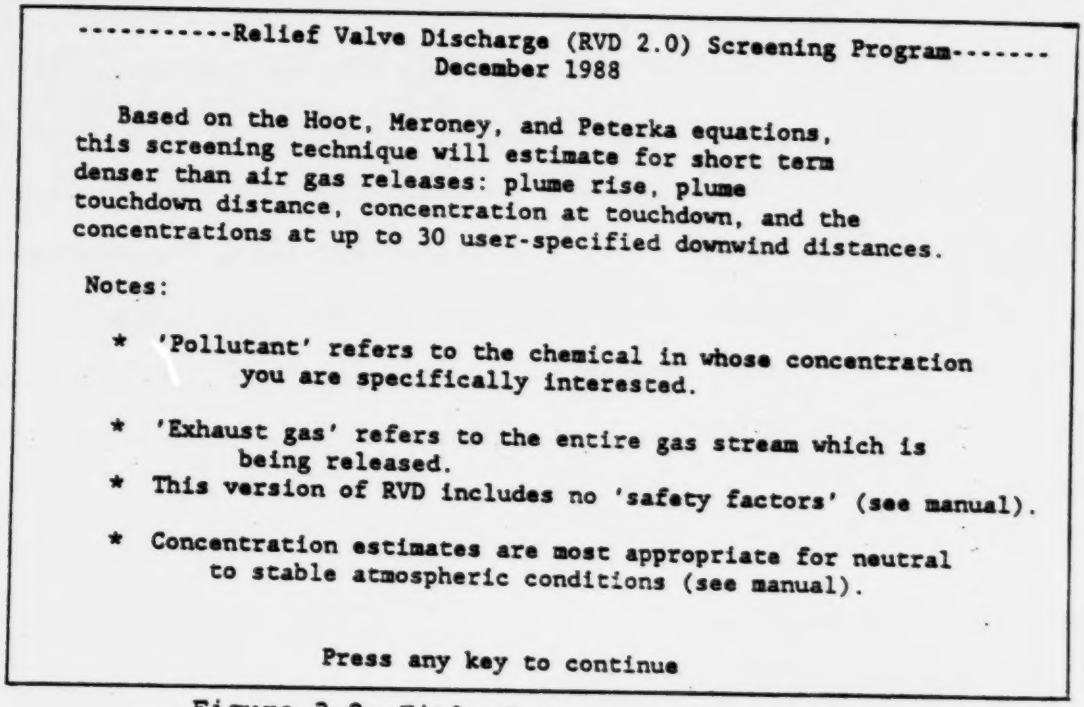

----------Relief Valve Discharge (RVD 2.0) Screening Program-------
December 1988
Based on the Hoot, Meroney, and Peterka equations,
this screening technique will estimate for short term
denser than air gas releases: plume rise, plume
touchdown distance, concentration at touchdown, and the
concentrations at up to 30 user-specified downwind distances.
Notes:
* 'Pollutant' refers to the chemical in whose concentration
you are specifically interested.
* 'Exhaust gas' refers to the entire gas stream which is
being released.
* This version of RVD includes no 'safety factors' (see manual).
* Concentration estimates are most appropriate for neutral
to stable atmospheric conditions (see manual).
Press any key to continue

Figure 3.2: Title Frame for the RVD Model

After the RVD model has been loaded into the computer's memory and the run begins, the title frame (Figure 3.2) will appear on the terminal screen. Press any key as directed to continue to the next frame.

```
DATA INPUT VIA KEYBOARD(0) OR FILE(1)? 0
Enter title (with out commas) -- Phosgene Release
Enter Emission Rate of Specific Pollutant (kg/sec) -- 6.26
Enter Exhaust Gas Exit Velocity (m/sec) -- 22
Enter Stack Diameter (m) -- .3
Enter Exit Gas Temperature (K) -- 293
Enter Stack Height (m) -- 24
Enter Pollutant Concentration (vol%) -- 100
Enter Pollutant Molecular Weight -- 99
You must choose to enter either:
   (1) Exhaust Gas Molecular Weight, or
   (2) Exhaust Gas Mass Flow Rate.

Choose (1) or (2) -- 1
Enter Exhaust Gas Molecular Weight -- 99
Enter duration of release (min) -- 10
Enter desired averaging time (min) -- 15
Enter pressure inside vessel (atm) -- 1.01
```

Figure 3.3: Source Data Input via Keyboard

Figure 3.3 shows the beginning of the data input procedure. The user is given an option to input the source and meteorological data by way of a data file or interactively from the keyboard. In this example, the user does not have a data file created and wishes to enter the data at the keyboard. The response "0" begins the data entry procedure. Values for the source parameters described in Section 3.2 are requested sequentially as shown in the above figure.

```
#1. Phosgene Release
#2. Pollutant emission rate (kg/sec) =  6.26
#3. Exit gas velocity (m/sec)=  22
#4. Diameter (m) =  .3
#5. Exit Temperature (K)=  293
#6. Stack Height (m) =  24
#7. Pollutant Concentration (volume %) =  100
#8. Pollutant Molecular Weight =  99
#9. Exhaust Gas Molecular Weight =  99
#10. Exhaust Gas Mass Flow Rate (kg/sec) =  6.26
#11. Duration of Release (min) =  10
#12. Averaging Time (min) =  15
#13. Release Pressure (atm, absolute) =  1.01

If a value is incorrect, enter its number.
If all values are OK, enter 0. -- 0
```

Figure 3.4: Source Data Echoed

After the source data have been entered, the program will echo or reprint these data to the screen, as shown in Figure 3.4. This allows the user to make any corrections that may be necessary. Each time a correction is made, the source parameter listing is reprinted. It should be noted that the program performs a calculation to assure that the exhaust gas mass flow rate and molecular weight are consistent with the reported contaminant flow rate and volume percent, and that the results of this calculation are reflected in this table.

Once the source data have been correctly entered, the program performs a quick check to determine whether the input

exit velocity is consistent with the exhaust gas mass flow rate. If there is substantial disagreement, the program will warn the user of this problem, and allow continuation or termination of the model run. As was mentioned before, this message can be ignored if attempts are being made to model an aerosol release, but if this is not the case, the user may want to check the accuracy of the input data.

```
Enter desired number of wind speeds (maximum=21) -- 5
Enter  5  wind speed(s) (m/sec) separated by <Enter>s
? 1? 1.5? 2? 2.5? 3
Here are your wind speeds:
     1.0000
     1.5000
     2.0000
     2.5000
     3.0000
Is everything OK? (y or n) -- y
```

Figure 3.5: Wind Speed Data Input via Keyboard

Next, the program will ask for the meteorological data, beginning with the number of wind speeds to be examined as well as each individual wind speed value (Figure 3.5). Here, 5 wind speed values ranging from 1 to 3 m/sec are to be analyzed.

```
Number of downwind receptor distances (max = 30)? 2
Enter 2  specific distances (m) separated by <Enters>
? 120? 210
Receptor distances are:
   120.0000
   210.0000
Are values correct? (y or n) -- y
Ambient temperatures (degrees K) default to:

(A) 298   (B) 298   (C) 298   (D) 298   (E) 298   (F) 298

Would you like to enter your own? (y or n) -- n
Wind speed profile exponents are for (0) urban
 or (1) rural conditions - choose one:0


OUTPUT -- HARD COPY(1) OR SCROLL TO SCREEN(0)? 0
```

Figure 3.6: Receptor Locations, Meteorological Data Input via Keyboard and Print/File Options

Figure 3.6 shows the remaining input steps from the number of receptors through the wind speed profile exponents. The user may use the default values provided for temperatures, wind speed profile exponents, or u./u values; or the user may choose to enter site-specific values. At the end of the data input session, the user may choose to have the model output sent to the printer or scrolled to the screen. Here, the choice is made to send it to the screen.

Figures 3.7(a) through 3.7(e), shown on the following pages, illustrate how the program output would look if scrolled to the screen. After the data have been previewed at the terminal, the program provides the user with the choice of creating a printed copy of the output. In addition, the input data just entered via the keyboard may be optionally saved to a disk file for later use (see Figure 3.7(e)).

After all data have been entered, a summary of those data will be printed on the terminal screen as in Figure 3.7(a) below.

```
Phosgene Release                07-28-1988

                                     Input Data

Pollutant emission rate (kg/sec) = 6.26
Exit gas velocity (m/sec)= 22
Exit Temperature (K)= 293
Stack Height (m) = 24      Diameter (m) = .3
Pollutant Concentration (volume %) = 100
Exhaust Gas Density (kg/m3) = 4.107433
Exhaust Gas Molecular Weight = 99
Exhaust Gas Mass Flow Rate (kg/sec) = 6.26
Pollutant Molecular Weight = 99
Release duration (min) = 10  Av. Time (min) = 15
Release pressure (atm) = 1.01
Wind Speeds (m/sec) = 1.0    1.5    2.0    2.5    3.0
Distances (m) = 120    210
Ambient Temperature (K) = 298  298  298  298  298  298
Urban Wind Speed Profile Exponents


                    Press any key to continue
```

Figure 3.7(a): Echoed Input Data

When the user presses a key, the input data summary will be replaced by a table summarizing the results of the initial testing performed by the model (Figure 7(b), below). The wind speed/stability combinations which result in dense gas behavior are indicated by the number "1", and those which do not are indicated by the number "0". The "2" represents those conditions, atmospheric stability class and wind speed combinations, which do not occur. These combinations are determined in accordance with the scheme described by Turner'.

Stability Class

Wind Speed	1	2	3	4	5	6
1.0	1	1	1	1	2	1
1.5	1	1	1	1	2	1
2.0	1	1	1	1	1	1
2.5	1	1	1	1	1	1
3.0	1	1	1	1	1	1

(0=Non-Dense Behavior 1=Dense Gas Behavior
2=Combinations that cannot occur)

Press any key to continue

Figure 3.7(b): Dense Gas Effects as a Function of Meteorological Conditions

The next table displayed on the terminal screen (Figure 3.7(c), below) displays the release Richardson numbers calculated by the program for each meterological combination. The matrix is set up in the same fashion as in Figure 3.7(b). Numbers with calculated values above 999999.9 are printed as 999999.9.

Release Richardson Numbers

Stability Class

Wind Speed	1	2	3	4	5	6
1.0	29980.0	29980.0	28696.0	27466.9	26290.6	26290.6
1.5	8883.0	8883.0	8502.5	8138.4	7789.8	7789.8
2.0	3747.5	3747.5	3587.0	3433.4	3286.3	3286.3
2.5	1918.7	1918.7	1836.5	1757.9	1682.6	1682.6
3.0	1110.4	1110.4	1062.8	1017.3	973.7	973.7

Press any key to continue

Figure 3.7(c): Release Richardson Number Matrix

The estimated plume touchdown distances and centerline ground-level concentrations are displayed on the next page in Figure 3.7(d) for each combination of wind speed and stability class for which dense gas behavior was predicted to occur. The concentrations are given in micrograms per cubic meter and in parts per million (assuming an ambient temperature of 298 K).

For screening purposes, all concentrations should be multiplied by a factor of 2.0 prior to comparing them with a significance level or health effects threshold concentration.

Dense Plume Trajectory

Stability Class	Wind Speed (m/sec)	Plume Rise (m)	Touchdown Distance (m)	Touchdown Concentration (ug/m3)	(ppm)
1	1.0	9.9	31.91	0.12520E+08	0.30984E+04
1	1.5	8.6	53.08	0.93584E+07	0.23160E+04
1	2.0	7.8	76.49	0.75725E+07	0.18740E+04
1	2.5	7.3	101.81	0.64065E+07	0.15855E+04
1	3.0	6.8	128.80	0.55780E+07	0.13804E+04
2	1.0	9.9	31.91	0.12520E+08	0.30984E+04
2	1.5	8.6	53.08	0.93584E+07	0.23160E+04
2	2.0	7.8	76.49	0.75725E+07	0.18740E+04
2	2.5	7.3	101.81	0.64065E+07	0.15855E+04
2	3.0	6.8	128.80	0.55780E+07	0.13804E+04
3	1.0	9.7	33.70	0.12138E+08	0.30038E+04
3	1.5	8.5	56.10	0.90642E+07	0.22432E+04
3	2.0	7.7	80.89	0.73296E+07	0.18139E+04
3	2.5	7.2	107.71	0.61980E+07	0.15338E+04
3	3.0	6.7	136.31	0.53942E+07	0.13349E+04
4	1.0	9.6	35.59	0.11766E+08	0.29118E+04
4	1.5	8.4	59.30	0.87784E+07	0.21724E+04
4	2.0	7.6	85.55	0.70938E+07	0.17555E+04
4	2.5	7.1	113.96	0.59956E+07	0.14838E+04
4	3.0	6.6	144.27	0.52160E+07	0.12908E+04
5	2.0	7.5	90.48	0.68650E+07	0.16989E+04
5	2.5	7.0	120.58	0.57993E+07	0.14352E+04
5	3.0	6.6	152.70	0.50432E+07	0.12481E+04
6	1.0	9.4	37.60	0.11405E+08	0.28223E+04
6	1.5	8.3	62.69	0.85007E+07	0.21037E+04
6	2.0	7.5	90.48	0.68650E+07	0.16989E+04
6	2.5	7.0	120.58	0.57993E+07	0.14352E+04
6	3.0	6.6	152.70	0.50432E+07	0.12481E+04

Figure 3.7(d): Plume Touchdown Concentration Table
(For screening, all concentrations should be multiplied by 2.0)

The final output scrolled to the screen will be the post-touchdown ground level centerline concentration estimates at the user specified receptor locations. In this example, two receptors were located at 120 and 210 meters downwind, respectively (see Figure 3.7(e)). Note that ground-level concentration estimates for receptors upwind of the plume touchdown point are assumed to be equal to zero and are not presented in these tables. Again, for screening purposes, all concentrations should be multiplied by 2.0.

After all receptor concentration estimates have been displayed, the user is given printing and filing options. In this example, the user chooses not to create a printed copy of the results and to save the source and meteorological input data entered at the keyboard in the file "a:phos.dat".

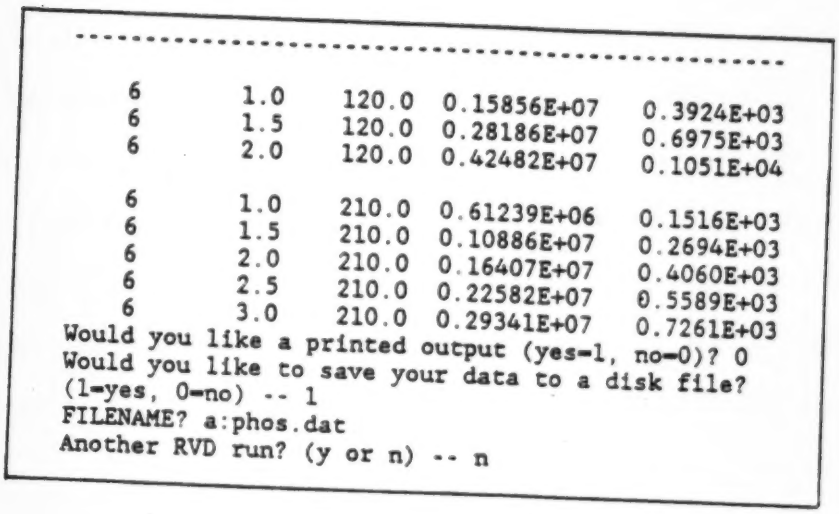
Concentrations at Specific Receptor Distances

Stability Class	Wind Speed (m/sec)	Distance (m)	Concentration (ug/m3)	(ppm)
1	1.0	120.0	0.13170E+07	0.3259E+03
1	1.5	120.0	0.23386E+07	0.5787E+03
1	2.0	120.0	0.35219E+07	0.8716E+03
1	2.5	120.0	0.48444E+07	0.1199E+04
1	1.0	210.0	0.50866E+06	0.1259E+03
1	1.5	210.0	0.90322E+06	0.2235E+03
1	2.0	210.0	0.13602E+07	0.3366E+03
1	2.5	210.0	0.18710E+07	0.4630E+03
1	3.0	210.0	0.24297E+07	0.6013E+03

Figure 3.7(e): Receptor Concentration Table and Print/File Options (For screening, all concentrations should be multiplied by 2.0)

2	1.0	120.0	0.13170E+07	0.3259E+03
2	1.5	120.0	0.23386E+07	0.5787E+03
2	2.0	120.0	0.35219E+07	0.8716E+03
2	2.5	120.0	0.48444E+07	0.1199E+04
2	1.0	210.0	0.50866E+06	0.1259E+03
2	1.5	210.0	0.90322E+06	0.2235E+03
2	2.0	210.0	0.13602E+07	0.3366E+03
2	2.5	210.0	0.18710E+07	0.4630E+03
2	3.0	210.0	0.24297E+07	0.6013E+03
3	1.0	120.0	0.14010E+07	0.3467E+03
3	1.5	120.0	0.24887E+07	0.6159E+03
3	2.0	120.0	0.37489E+07	0.9278E+03
3	2.5	120.0	0.51576E+07	0.1276E+04
3	1.0	210.0	0.54110E+06	0.1339E+03
3	1.5	210.0	0.96117E+06	0.2379E+03
3	2.0	210.0	0.14479E+07	0.3583E+03
3	2.5	210.0	0.19920E+07	0.4930E+03
3	3.0	210.0	0.25872E+07	0.6403E+03
4	1.0	120.0	0.14904E+07	0.3688E+03
4	1.5	120.0	0.26484E+07	0.6554E+03
4	2.0	120.0	0.39907E+07	0.9876E+03
4	2.5	120.0	0.54914E+07	0.1359E+04
4	1.0	210.0	0.57563E+06	0.1425E+03
4	1.5	210.0	0.10229E+07	0.2531E+03
4	2.0	210.0	0.15413E+07	0.3814E+03
4	2.5	210.0	0.21209E+07	0.5249E+03
4	3.0	210.0	0.27551E+07	0.6818E+03
5	2.0	120.0	0.42482E+07	0.1051E+04
5	2.0	210.0	0.16407E+07	0.4060E+03
5	2.5	210.0	0.22582E+07	0.5589E+03
5	3.0	210.0	0.29341E+07	0.7261E+03

Figure 3.7(e), continued: Receptor Concentration Table and Print/File Options (For screening, all concentrations should be multiplied by 2.0)



```
-----------------------------------------------------

     6        1.0     120.0   0.15856E+07    0.3924E+03
     6        1.5     120.0   0.28186E+07    0.6975E+03
     6        2.0     120.0   0.42482E+07    0.1051E+04

     6        1.0     210.0   0.61239E+06    0.1516E+03
     6        1.5     210.0   0.10886E+07    0.2694E+03
     6        2.0     210.0   0.16407E+07    0.4060E+03
     6        2.5     210.0   0.22582E+07    0.5589E+03
     6        3.0     210.0   0.29341E+07    0.7261E+03
Would you like a printed output (yes=1, no=0)? 0
Would you like to save your data to a disk file?
(1=yes, 0=no) -- 1
FILENAME? a:phos.dat
Another RVD run? (y or n) -- n
```

Figure 3.7(e): Receptor Concentration Table and Print/File Options (For screening, all concentrations should be multiplied by a factor of 2.0)

3.5.2 Batch Mode

This example illustrates the use of the RVD model in the batch mode. The source in question is a vinyl chloride release from a pressure relief valve that is depressurized through a stack and routed to the atmosphere. This source emits 15.12 kg/sec of 100 percent vinyl chloride for 3 minutes. The stack parameters include an exit velocity of 100 m/sec, an exit diameter of 0.25 m, a stack height of 12 m, and an exit temperature of 259 K. Since the release routes through a stack, the "release pressure" to be used is atmospheric.

Six wind speeds are to be examined ranging from 1.0 to 5.0 m/sec. Two receptors are located at 100 and 500 m downwind. Figure 3.8 is the data input file for this example run. The data were saved under the file name "a:vinyl.dat".

```
Vinyl Chloride
 15.12
 100
 .25
 259
 12
 100
 62.5
 15.12
 62.5
 3
 15
 1
 7
 1  1.5  2  2.5  3.1  3.6  5
 2
 100  500
 298  298  298  298  298  298
 0
```

Figure 3.8: Input Data File, Example 3.5.2

After initiating execution by typing the command "RVD" at the DOS prompt, the title frame (Figure 3.2) appears on the terminal screen. As execution continues (Figure 3.9), the user tells the program to access the input data via the data file "a:vinyl.dat", the user choosing to have the model output sent directly to the printer.

```
DATA INPUT VIA KEYBOARD(0) OR FILE(1)? 1
FILENAME? a:vinyl.dat


OUTPUT -- HARD COPY(1) OR SCROLL TO SCREEN(0)? 1
```

Figure 3.9: Interactive Procedure for Batch Mode

Figure 3.10 is the resulting hard copy of this model run. As seen before in Figure 3.7, the resulting output is a series of tables beginning with the input data and concluding with the concentration estimates at plume touchdown and specific receptor locations, as before. To determine the worst-case ambient impact of the pollutant, the user should compare concentrations keeping in mind their locations with respect to a specified plant fenceline. For example, if the fenceline in this case is located 100m downwind, a review of the touchdown concentrations at touchdown distances in excess of 100m indicates that the maximum

concentration is about 2.07 g/m^3 (occurring in stability classes A and B with 1.5 m/sec winds at 104m downwind). A review of the table giving fenceline (100m) concentrations confirms that this concentration exceeds any fenceline value. For screening purposes, all concentration values should be multiplied by a factor of 2.0 prior to comparing them with a significance level or health effects threshold.

Vinyl Chloride 07-28-1988

Input Data

Pollutant emission rate (kg/sec) = 15.12
Exit gas velocity (m/sec)= 100
Exit Temperature (K)= 259
Stack Height (m) = 12 Diameter (m) = .25
Pollutant Concentration (volume %) = 100
Exhaust Gas Density (kg/m3) = 2.933481
Exhaust Gas Molecular Weight = 62.5
Exhaust Gas Mass Flow Rate (kg/sec) = 15.12
Pollutant Molecular Weight = 62.5
Release duration (min) = 3 Av. Time (min) = 15
Release pressure (atm) = 1
Wind Speeds (m/sec) = 1.0 1.5 2.0 2.5 3.1 3.6 5.0
Distances (m) = 100 500
Ambient Temperature (K) = 298 298 298 298 298 298
Urban Wind Speed Profile Exponents

Dense Gas Behavior

Stability Class

Wind Speed	1	2	3	4	5	6
1.0	1	1	1	1	2	1
1.5	1	1	1	1	2	1
2.0	1	1	1	1	1	1
2.5	1	1	1	1	1	1
3.1	2	1	1	1	1	2
3.6	2	1	1	1	1	2
5.0	2	1	1	1	1	2

(0=Non-Dense Behavior 1=Dense Gas Behavior
2=Combinations that cannot occur)

Figure 3.10: Hard Copy of Example Run Output

Release Richardson Numbers

Stability Class

Wind Speed	1	2	3	4	5	6
1.0	80806.7	80806.7	80073.4	79346.8	78626.8	78626.8
1.5	23942.7	23942.7	23725.5	23510.2	23296.8	23296.8
2.0	10100.8	10100.8	10009.2	9918.3	9828.3	9828.3
2.5	5171.6	5171.6	5124.7	5078.2	5032.1	5032.1
3.1	2712.5	2712.5	2687.8	2663.4	2639.3	2639.3
3.6	1732.0	1732.0	1716.3	1700.7	1685.2	1685.2
5.0	646.5	646.5	640.6	634.8	629.0	629.0

Dense Plume Trajectory

Stability Class	Wind Speed (m/sec)	Plume Rise (m)	Touchdown Distance (m)	Touchdown Concentration (ug/m3)	(ppm)
1	1.0	39.0	67.70	0.24883E+07	0.97542E+03
1	1.5	34.1	103.94	0.20796E+07	0.81522E+03
1	2.0	30.9	141.14	0.18261E+07	0.71582E+03
1	2.5	28.7	179.14	0.16481E+07	0.64607E+03
2	1.0	39.0	67.70	0.24883E+07	0.97542E+03
2	1.5	34.1	103.94	0.20796E+07	0.81522E+03
2	2.0	30.9	141.14	0.18261E+07	0.71582E+03
2	2.5	28.7	179.14	0.16481E+07	0.64607E+03
2	3.1	26.7	225.63	0.14909E+07	0.58443E+03
2	3.6	25.4	265.03	0.13893E+07	0.54459E+03
2	5.0	22.8	378.12	0.11865E+07	0.46513E+03
3	1.0	38.9	68.35	0.24784E+07	0.97154E+03
3	1.5	34.0	104.95	0.20712E+07	0.81189E+03
3	2.0	30.9	142.52	0.18185E+07	0.71285E+03
3	2.5	28.6	180.89	0.16412E+07	0.64335E+03
3	3.1	26.7	227.85	0.14845E+07	0.58193E+03
3	3.6	25.4	267.65	0.13833E+07	0.54224E+03
3	5.0	22.7	381.88	0.11813E+07	0.46307E+03

Figure 3.10, continued: Hard Copy of Example Run Output (For screening, all concentrations should be multiplied by a factor of 2.0)

4	1.0	38.7	69.01	0.24686E+07	0.96767E+03
4	1.5	33.9	105.97	0.20627E+07	0.80858E+03
4	2.0	30.8	143.91	0.18110E+07	0.70989E+03
4	2.5	28.6	182.67	0.16343E+07	0.64064E+03
4	3.1	26.6	230.10	0.14782E+07	0.57944E+03
4	3.6	25.3	270.30	0.13773E+07	0.53990E+03
4	5.0	22.7	385.68	0.11761E+07	0.46102E+03
5	2.0	30.7	145.32	0.18034E+07	0.70694E+03
5	2.5	28.5	184.46	0.16274E+07	0.63794E+03
5	3.1	26.5	232.36	0.14718E+07	0.57696E+03
5	3.6	25.2	272.97	0.13713E+07	0.53756E+03
5	5.0	22.6	389.52	0.11709E+07	0.45898E+03
6	1.0	38.6	69.68	0.24587E+07	0.96382E+03
6	1.5	33.8	107.00	0.20543E+07	0.80528E+03
6	2.0	30.7	145.32	0.18034E+07	0.70694E+03
6	2.5	28.5	184.46	0.16274E+07	0.63794E+03

Concentrations at Specific Receptor Distances

Stability Class	Wind Speed (m/sec)	Distance (m)	Concentration (ug/m3)	(ppm)
1	1.0	100.0	0.12821E+07	0.5026E+03
1	1.0	500.0	0.83113E+05	0.3258E+02
1	1.5	500.0	0.14398E+06	0.5644E+02
1	2.0	500.0	0.21266E+06	0.8336E+02
1	2.5	500.0	0.28785E+06	0.1128E+03
2	1.0	100.0	0.12821E+07	0.5026E+03
2	1.0	500.0	0.83113E+05	0.3258E+02
2	1.5	500.0	0.14398E+06	0.5644E+02
2	2.0	500.0	0.21266E+06	0.8336E+02
2	2.5	500.0	0.28785E+06	0.1128E+03
2	3.1	500.0	0.38545E+06	0.1511E+03
2	3.6	500.0	0.47223E+06	0.1851E+03
2	5.0	500.0	0.73793E+06	0.2893E+03

Figure 3.10, continued: Hard Copy of Example Run Output (For screening, all concentrations should be multiplied by a factor of 2.0)

3	1.0	100.0	0.12980E+07	0.5088E+03
3	1.0	500.0	0.84146E+05	0.3299E+02
3	1.5	500.0	0.14577E+06	0.5714E+02
3	2.0	500.0	0.21531E+06	0.8440E+02
3	2.5	500.0	0.29143E+06	0.1142E+03
3	3.1	500.0	0.39025E+06	0.1530E+03
3	3.6	500.0	0.47811E+06	0.1874E+03
3	5.0	500.0	0.74713E+06	0.2929E+03
4	1.0	100.0	0.13141E+07	0.5151E+03
4	1.0	500.0	0.85191E+05	0.3340E+02
4	1.5	500.0	0.14758E+06	0.5785E+02
4	2.0	500.0	0.21799E+06	0.8545E+02
4	2.5	500.0	0.29506E+06	0.1157E+03
4	3.1	500.0	0.39511E+06	0.1549E+03
4	3.6	500.0	0.48407E+06	0.1898E+03
4	5.0	500.0	0.75645E+06	0.2965E+03
5	2.0	500.0	0.22070E+06	0.8651E+02
5	2.5	500.0	0.29873E+06	0.1171E+03
5	3.1	500.0	0.40003E+06	0.1568E+03
5	3.6	500.0	0.49010E+06	0.1921E+03
5	5.0	500.0	0.76588E+06	0.3002E+03
6	1.0	100.0	0.13305E+07	0.5215E+03
6	1.0	500.0	0.86250E+05	0.3381E+02
6	1.5	500.0	0.14941E+06	0.5857E+02
6	2.0	500.0	0.22070E+06	0.8651E+02
6	2.5	500.0	0.29873E+06	0.1171E+03

Figure 3.10, continued: Hard Copy of Example Run Output (For screening, all concentrations should be multiplied by a factor of 2.0)

REFERENCES

1. Hoot, T.G., R.N. Meroney, and J.A. Peterka, 1973: Wind Tunnel Tests of Negatively Buoyant Plumes. EPA-650/3-74-003, US Environmental Protection Agency, Research Triangle Park, NC 27711.

2. Puttock, J.S., D.R. Blackmore, and G.W. Colenbrander, 1982: "Field Experiments on Dense Gas Dispersion,"in Dense Gas Dispersion (R.E. Britter and R.F. Griffiths, ed.), Elsevier Scientific Publishing Comp., New York.

3. Environmental Protection Agency, 1988: A Dispersion Model for Elevated Dense Gas Jet Chemical Releases, Volume I. EPA-450/2-88-006a, US Environmental Protection Agency, Research Triangle Park, NC 27711.

4. Turner, D. B., Workbook of Atmospheric Dispersion Estimates. US Environmental Protection Agency, Research Triangle Park, NC 27711.

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APPENDIX

Program Code

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10 '-------------Relief Valve Discharge (RVD) Screening Program----------
20 '                              Version 2.0
30 '                              Developed by
50 '                      US EPA  Source Receptor Analysis Branch
51 '                          Model Application Section
60 '                          Original version May, 1986
70 '                      Version 2.0 created 12/88 by Dave Guinnup
80 '
90 '   Based on the Hoot, Meroney, and Peterka equations, this screening
100 'technique will estimate for short term denser than air gas releases:
110 'plume rise, plume touchdown distance, concentration at touchdown, and
120 'the concentrations at up to 30 downwind distances specified by the user.
130 '
140 'Note:  While the US EPA does not warrant the use of this program,
150 '         the Agency does provide it as a general service.
160 '
170 '      ALSO NOTE THAT THE CONSERVATIVE "FACTOR OF 5" IS NO LONGER USED
180 '                    IN THIS VERSION OF RVD !!
190 '
200 ' Additional information can be obtained by contacting Dave Guinnup
210 ' at (919) 541-5690 or FTS 629-5690.
220 '
230 '
240 ' Citations:
250 ' Hoot, T.G., R.N. Meroney, and J.A. Peterka (1973). "Wind Tunnel Tests
260 '      of Negatively Buoyant Plumes," EPA-650/3-74-003, U.S. Environmental
270 '      Protection Agency, Research Triangle Park, NC, 104 p.
280 '
290 ' Puttock, J.S., D.R. Blackmore, and G.W. Colenbrander (1982). "Field
300 '      Experiments on Dense Gas Dispersion," Dense Gas Dispersion
310 '      (R.E. Britter and R.F. Griffiths, ed.), Elsevier Scientific
311 '      Publishing Comp., New York, pp 13-41.
320 '
330 KEY OFF
340 LET FMT$ = " #####.#### #####.#### #####.#### #####.####"
350 FT1$= "    #      ###.#  #####.#  #.#####^^^^   #.####^^^^"
360 FT3$="###.#    #   #   #   #   #   #"
370 FT$="    #      ###.#  ###.# ####.##   #.#####^^^^   #.#####^^^^"
380 FT2$="####.#"
390 FT4$="  ##.#    ######.#  ######.#  ######.#  ######.#  ######.#  ######.#"
400 '
410 '  INITIALIZE ARRAYS
420 '
430 DIM ARHO(6),DEL(6),RI(21,6),A(21,6),SG(6),TA(6),RV(21,6),FR(6),FRH(21,6)
440 DIM CALH(6),VHS(21,6),CRH(21,6),DRH(21,6),MWH(21,6),TH(21,6)
450 DIM DELTA(21,6),DISTH(21,6),DISTD(21,6),DISTF(21,6),DIST(30)
460 DIM CONCD(21,6),CONC(21,6),P(6),USTAR(6),V(21),HA(21,6),L(6)
470 COLOR 3,1:CLS
480 PRINT "-----------Relief Valve Discharge (RVD 2.0) Screening Program------- "
540 PRINT "                              December 1988
550 PRINT "
560 PRINT "   Based on the Hoot, Meroney, and Peterka equations,"
570 PRINT "this screening technique will estimate for short term"
580 PRINT "denser than air gas releases: plume rise, plume"
590 PRINT "touchdown distance, concentration at touchdown, and the"
591 PRINT "concentrations at up to 30 user-specified downwind distances."
610 PRINT "
750 PRINT " Notes:":PRINT "
760 PRINT "    * 'Pollutant' refers to the chemical in whose concentration"
770 PRINT "           you are specifically interested.":PRINT "
780 PRINT "    * 'Exhaust gas' refers to the entire gas stream which is"
781 PRINT "           being released."
782 PRINT "    * This version of RVD includes no 'safety factors' (see manual)."
783 PRINT "
784 PRINT "    * Concentration estimates are most appropriate for neutral "
785 PRINT "         to stable atmospheric conditions (see manual)."
790 GOSUB 4350
800 P(1)=.15:P(2)=.15:P(3)=.2:P(4)=.25:P(5)=.3:P(6)=.3
820 FOR I=1 TO 6:TA(I)=298:USTAR(I)=.06:NEXT I
830 LET D$=DATE$
840 INPUT "DATA INPUT VIA KEYBOARD(0) OR FILE(1)";INDAT
850 IF INDAT=0 GOTO 950
860 INPUT "FILENAME";FIL$
```

```
870 OPEN "I", #2, FIL$
880 INPUT #2,T$,QC,EXITV,D,T0,HS,VOL,MW,MO,MWC,TDUR,TAV,PR,NWS
890 FOR J=1 TO NWS:INPUT#2,V(J):NEXT J
900 INPUT#2,ISD:FOR J=1 TO ISD:INPUT#2,DIST(J):NEXT J
910 FOR J=1 TO 6:INPUT#2,TA(J):NEXT J
920 INPUT#2,IWSP
940 CLOSE#2:GOTO 1600
950 INPUT "Enter title (with out commas) -- ",T$:IF II=1 GOTO 1100
960 INPUT "Enter Emission Rate of Specific Pollutant (kg/sec) -- ",QC
961 IF II=1 THEN II2=1:GOTO 1030
970 INPUT "Enter Exhaust Gas Exit Velocity (m/sec) -- ",EXITV:IF II=1 GOTO 1100
980 INPUT "Enter Stack Diameter (m) -- ",D:IF II=1 GOTO 1100
990 INPUT "Enter Exit Gas Temperature (K) -- ",T0:IF II=1 GOTO 1100
1000 INPUT "Enter Stack Height (m) -- ",HS:IF II=1 GOTO 1100
1010 INPUT "Enter Pollutant Concentration (vol%) -- ",VOL:IF II=1 THEN II2=1:GOTO 1100
1011 INPUT "Enter Pollutant Molecular Weight -- ",MWC:IF II=1 THEN II2=1:GOTO 1100
1012 PRINT "You must choose to enter either:"
1013 PRINT "   (1) Exhaust Gas Molecular Weight, or"
1014 PRINT "   (2) Exhaust Gas Mass Flow Rate."
1015 PRINT "":INPUT "Choose (1) or (2) -- ",ICH
1016 ON ICH GOTO 1020,1080
1020 INPUT "Enter Exhaust Gas Molecular Weight -- ",MW
1030 MO=100!*QC*MW/VOL/MWC:IF II2=1 GOTO 1081:IF II=1 GOTO 1100
1031 GOTO 1082
1080 INPUT "Enter Exhaust Gas Mass Flow Rate (kg/sec) -- ",MO
1081 MW=MO*VOL*MWC/100!/QC:IF II=1 GOTO 1100
1082 INPUT "Enter duration of release (min) -- ",TDUR:IF II=1 GOTO 1100
1083 INPUT "Enter desired averaging time (min) -- ",TAV:IF II=1 GOTO 1100
1084 INPUT "Enter pressure inside vessel (atm) -- ",PR
1100 CLS:PRINT "#1. ";T$
1110 PRINT "#2. Pollutant emission rate (kg/sec) = ";QC
1120 PRINT "#3. Exit gas velocity (m/sec)= ";EXITV
1130 PRINT "#4. Diameter (m) = ";D
1140 PRINT "#5. Exit Temperature (K)= ";T0
1150 PRINT "#6. Stack Height (m) = ";HS
1160 PRINT "#7. Pollutant Concentration (volume %) = ";VOL
1170 PRINT "#8. Pollutant Molecular Weight = ";MWC
1180 PRINT "#9. Exhaust Gas Molecular Weight = ";MW
1190 PRINT "#10. Exhaust Gas Mass Flow Rate (kg/sec) = ";MO
1191 PRINT "#11. Duration of Release (min) = ";TDUR
1192 PRINT "#12. Averaging Time (min) = ";TAV
1193 PRINT "#13. Release Pressure (atm, absolute) = ";PR
1200 PRINT ""
1210 PRINT "If a value is incorrect, enter its number."
1220 INPUT "If all values are OK, enter 0. -- ",ICOR
1230 IF ICOR = 0 GOTO 1250
1240 II=1:ON ICOR GOTO 950,960,970,980,990,1000,1010,1011,1020,1080,1082,1083,1084
1250 CLS:INPUT "Enter desired number of wind speeds (maximum=21) -- ",NWS
1260 PRINT "Enter ";NWS;" wind speed(s) (m/sec) separated by <Enter>s"
1270 FOR IJ=1 TO NWS
1271 INPUT;V(IJ):IF V(IJ)>=1! GOTO 1272 ELSE PRINT "  No wind speeds less than 1.0 m/s are
allowed!":GOTO 1271
1272 NEXT IJ
1280 PRINT ""
1290 PRINT "Here are your wind speeds:"
1300 FOR IJ=1 TO NWS
1310 PRINT USING FMT$;V(IJ):NEXT IJ
1320 INPUT "Is everything OK? (y or n) -- ",ANS$
1330 IF ANS$ <> "y" AND ANS$ <> "Y" GOTO 1250
1340 CLS:INPUT "Number of downwind receptor distances (max = 30)";ISD
1350 IF ISD>1 GOTO 1390
1360 INPUT "Enter one specific distance (m) -- ",DIST(1)
1370 PRINT USING FMT$;DIST(1)
1380 GOTO 1430
1390 PRINT "Enter";ISD;" specific distances (m) separated by <Enters>"
1400 FOR J=1 TO ISD:INPUT;DIST(J):NEXT J
1410 PRINT "":PRINT "Receptor distances are:"
1420 FOR J=1 TO ISD:PRINT USING FMT$;DIST(J):NEXT J
1430 INPUT "Are values correct? (y or n) -- ",ANS$
1440 IF ANS$ <> "Y" AND ANS$ <> "y" GOTO 1390
1450 PRINT "Ambient temperatures (degrees K) default to:"
1460 PRINT ""
1470 PRINT "(A) 298   (B) 298   (C) 298   (D) 298   (E) 298   (F) 298"
```

```
1480 PRINT ""
1490 INPUT "Would you like to enter your own? (y or n) -- ",ANS$
1500 IF ANS$ <> "Y" AND ANS$ <> "y" GOTO 1580
1510 PRINT "Enter the ambient air temperatures (K) for each stability"
1520 PRINT " separated by <Enter>s"
1530 FOR I = 1 TO 6:INPUT;TA(I):NEXT I
1540 PRINT ""
1550 PRINT USING FMT$;TA(1),TA(2),TA(3),TA(4),TA(5),TA(6)
1560 INPUT "Are values correct? (y or n) -- ",ANS$
1570 IF ANS$ <> "Y" AND ANS$ <> "y" GOTO 1510
1580 PRINT "Wind speed profile exponents are for (0) urban"
1590 INPUT " or (1) rural conditions - choose one:",IWSP
1600 IF IWSP = 1 THEN P(1)=.07:P(2)=.07:P(3)=.1:P(4)=.15:P(5)=.35:P(6)=.55
1680 PRINT ""
1808 TRAT = TDUR/TAV
1809 IF TDUR > TAV THEN TRAT=1!:IF TAV < 60 THEN TRAT=TRAT*(60/TAV)^0.2
1810 RHO=1.183*MW/29!*298/TO
1811 EXITVC=PR*4*MO/RHO/3.14159/D^2
1820 IF ABS((EXITV-EXITVC)/EXITVC)<.05 GOTO 1837
1831 PRINT "Velocity check calculates:"
1832 PRINT "         ";EXITVC;"    vs input velocity of                    "
1833 PRINT "         ";EXITV
1834 PRINT ""
1835 INPUT " Would you like to continue the calculation anyway? (y or n) -- ",ANS$
1836 IF ANS$ <> "y" AND ANS$ <> "Y" GOTO 4320
1837 VM=29!/(1183!)
1838 CFM=EXITV*3.14159*D^2/4!
1840 PRINT ""
1850 INPUT "OUTPUT -- HARD COPY(1) OR SCROLL TO SCREEN(0)";ICOP
1860 IF ICOP=0 GOTO 1890
1870 OPEN "O", #1, "LPT1:":IPR=1
1880 GOTO 1920
1890 OPEN "O", #1, "SCRN:":COLOR 7,4:CLS
1920 PRINT #1, T$;"            "D$
1940 PRINT #1, " "
1950 PRINT #1, "                                    Input Data"
1960 PRINT #1, " "
1970 PRINT #1, "Pollutant emission rate (kg/sec) = ";QC
1980 PRINT #1, "Exit gas velocity (m/sec)= ";EXITV
2000 PRINT #1, "Exit Temperature (K)= ";TO
2010 PRINT #1, "Stack Height (m) = ";HS;"    Diameter (m) = ";D
2020 PRINT #1, "Pollutant Concentration (volume %) = ";VOL
2030 PRINT #1, "Exhaust Gas Density (kg/m3) = ";RHO
2040 PRINT #1, "Exhaust Gas Molecular Weight = ";MW
2050 PRINT #1, "Exhaust Gas Mass Flow Rate (kg/sec) = ";MO
2060 PRINT #1, "Pollutant Molecular Weight = ";MWC
2071 PRINT #1, "Release duration (min) = ";TDUR;" Av. Time (min) = ";TAV
2072 PRINT #1, "Release pressure (atm) = ";PR
2080 PRINT #1, "Wind Speeds (m/sec) = ";
2090 FOR I=1 TO NWS-1:PRINT #1, USING "##.#   ";V(I);
2100 NEXT I:PRINT #1, USING "##.#";V(NWS)
2110 IF ISD > 1 GOTO 2140
2120 PRINT #1, "Distance (m) = ";DIST(1)
2130 GOTO 2160
2140 PRINT #1, "Distances (m) = ";
2150 FOR I=1 TO ISD:PRINT #1, DIST(I);SPC(2);:NEXT I:PRINT #1,""
2160 PRINT #1, "Ambient Temperature (K) = ";TA(1);TA(2);TA(3);TA(4);TA(5);TA(6)
2170 IF IWSP=0 THEN PRINT #1, "Urban Wind Speed Profile Exponents":GOTO 2200
2180 PRINT #1, "Rural Wind Speed Profile Exponents"
2200 IF ICALC=1 GOTO 3160
2210 '
2220 ' Acceleration of gravity (m/sec2)
2230 LET G = 9.8
2260 CONCG=5000!*MWC/VM
2270 '
2280 ' Because the ratio (friction velocity)/(wind speed at z=10m) is used
2290 ' in place of the friction velocity, the "V(I)^2" term is included
2300 ' in the Richardson number calculations.
2310 '
2320 FOR J = 1 TO 6
2330 ' Calculate the ambient air density which is dependent upon temperature.
2340 LET ARHO(J) = 1.183 * 298! / TA(J)
2350 LET DEL(J) = (RHO-ARHO(J))/ARHO(J)
```

```
2360 IF DEL(J)>0 GOTO 2380
2370 FOR I=1 TO NWS:A(I,J)=0:NEXT I
2380 NEXT J
2400 FOR J = 1 TO 6
2410 FOR I = 1 TO NWS
2420 ' Richardson number test
2430 ' If RI is less than or equal to 30 then treat as a stack source.
2440 ' Wind speed at stack height.
2450 LET VHS(I,J) = V(I)*(HS/10!)^P(J)
2460 LET RI(I,J) = (G*DEL(J)*HO)/(VHS(I,J)*D*RHO*(USTAR(J)^2!)*(V(I)^2!))
2470 IF RI(I,J) <= 30! THEN GOTO 2500
2490 LET A(I,J) = 1
2500 NEXT I
2510 NEXT J
2520 ' The following loop identifies those wind speed and stability class
2530 ' combinations which do not exist based on the Turner (1964)
2540 ' definitions of stability classes (see the CRSTER User's Manual).
2550 FOR J=1 TO 6
2560 IF J=4 GOTO 2710
2570 FOR I=1 TO NWS
2580 IF J=3 GOTO 2700
2590 IF J > 1 THEN GOTO 2620
2600 IF V(I) >= 3.1 THEN A(I,J)=2
2610 GOTO 2700
2620 IF J = 2 THEN GOTO 2660
2630 IF J = 5 THEN GOTO 2680
2640 IF V(I) >= 3.1 THEN A(I,J)=2
2650 GOTO 2700
2660 IF V(I) >= 5.1 THEN A(I,J)=2
2670 GOTO 2700
2680 IF V(I) < 2.0 THEN A(I,J)=2
2690 IF V(I) > 5.0 THEN A(I,J)=2
2691 GOTO 2700
2692 IF V(I) < 2.0 THEN A(I,J)=2
2700 NEXT I
2710 NEXT J
2720 FOR J = 1 TO 6
2730 ' Vertical Densimetric Froude Number
2740 IF DEL(J)<=0 GOTO 2800
2750 LET FR(J) = EXITV*(((RHO/(RHO-ARHO(J)))/(G*D))^.5)
2760 ' Specific Gravity
2770 LET SG(J) = RHO/ARHO(J)
2780 ' Plume rise for negatively bouyant jet at calm conditions.
2790 LET CALH(J) = 2.96*FR(J)*D
2800 FOR I = 1 TO NWS
2810 IF A(I,J) <> 1 THEN GOTO 3120
2820 ' Wind speed at stack height.
2830 LET VHS(I,J) = V(I)*(HS/10!)^P(J)
2840 ' Velocity ratio.
2850 LET RV(I,J) = EXITV/VHS(I,J)
2860 ' Plume rise for negatively bouyant jet with crosswind.
2870 LET CRH(I,J) = 1.32*D*(RV(I,J)^.333)*(SG(J)^.333)*(FR(J)^.667)
2880 LET H = CRH(I,J)
2890 IF CRH(I,J) > CALH(J) THEN LET H = CALH(J)
2900 LET HA(I,J) = H
2910 ' Dilution Ratio at maximum plume rise.
2920 DRH(I,J)=((H^1.85)*VHS(I,J)*MW*298!*(D^.15))/(215000!*MO*.02445*TA(J))
2930 LET MWH(I,J) = (MW + 28.96*(DRH(I,J)-1!))/DRH(I,J)
2940 ' Temperature at maximum plume rise
2950 LET TH(I,J) = TA(J) - (MW*(TA(J)-TO)/(MWH(I,J)*DRH(I,J)))
2960 LET DELTA(I,J) = (MWH(I,J)*TA(J)/(TH(I,J)*28.96))-1!
2970 IF DELTA(I,J) <= .005 THEN GOTO 3110
2980 ' Distance to maximum plume rise.
2990 LET DISTH(I,J) = D*(FR(J)^2!)/RV(I,J)
3000 ' Concentration at plume touchdown.
3010 LET CONCD(I,J) = 5.100001E+09*QC*(2!*H+HS)^(-1.95)/(VHS(I,J)*(D^.05))
3020 ' Horizontal Densimetric Froude Number
3030 LET FRH(I,J) = VHS(I,J)*(((ARHO(J)/(RHO-ARHO(J)))/(G*D))^.5)
3040 LET CSQR = (((H/D)^3!*((2!+HS/H)^3!-1!)))^.5
3050 ' Distance to plume touchdown.
3060 LET DISTD(I,J) = DISTH(I,J)+.56*FRH(I,J)*CSQR*D*(RV(I,J)^(-.5))
3070 ' Distance at which 5000 ppm occurs.
3090 LET DISTF(I,J) = DISTD(I,J)*((CONCG/CONCD(I,J))^(-1.538))
```

```
3100 GOTO 3140
3110 LET A(I,J) = 0
3120 LET CONCD(I,J) = 0!
3130 LET DISTD(I,J) = 0!
3140 NEXT I
3150 NEXT J
3160 GOSUB 4350
3170 PRINT #1, CHR$(12)
3180 PRINT #1, "          Dense Gas Behavior"
3190 PRINT #1, " "
3200 PRINT #1, "           Stability  Class"
3210 PRINT #1, " "
3220 PRINT #1, " Wind    1   2   3   4   5   6"
3230 PRINT #1, "Speed"
3240 NLI=7
3250 FOR I=1 TO NWS
3270 FOR J=1 TO 6
3280 LET L(J)=0
3290 IF A(I,J)=1 THEN L(J)=1
3300 IF A(I,J)=2 THEN L(J)=2
3310 NEXT J
3320 PRINT #1, USING FT3$;V(I);L(1);L(2);L(3);L(4);L(5);L(6)
3330 NLI=NLI+1:IF NLI>20 THEN GOSUB 4350
3340 NEXT I
3350 PRINT #1, " "
3360 PRINT #1, "(0=Non-Dense Behavior   1=Dense Gas Behavior
3370 PRINT #1, "     2=Combinations that cannot occur)"
3380 PRINT #1, " "
3390 GOSUB 4350
3400 PRINT #1, "             Release Richardson Numbers"
3410 PRINT #1, " "
3420 PRINT #1, "                   Stability Class"
3430 PRINT #1, " "
3440 PRINT #1, "  Wind       1         2         3         4         5         6"
3450 PRINT #1, "  Speed"
3460 NLI=6
3470 FOR I=1 TO NWS
3480 IF ICALC=1 GOTO 3500
3490 FOR J=1 TO 6:IF RI(I,J)>1000000! THEN RI(I,J)=999999.9:NEXT J
3500 PRINT #1, USING FT4$;V(I);RI(I,1);RI(I,2);RI(I,3);RI(I,4);RI(I,5);RI(I,6)
3520 NEXT I
3530  N = 0
3540  FOR I = 1 TO NWS
3550  FOR J = 1 TO 6
3560  IF A(I,J) <> 1 THEN N=N + 1
3570  NEXT J
3580  NEXT I
3590  IF N = NWS*6 GOTO 4060
3600 GOSUB 4350
3610 PRINT #1, CHR$(12)
3620 PRINT #1, "             Dense Plume Trajectory"
3630 PRINT #1, "                                                    "
3640 PRINT #1, "Stability  Wind Plume Touchdown        Touchdown  "
3650 PRINT #1, "  Class    Speed  Rise  Distance      Concentration"
3660 PRINT #1, "          (m/sec)  (m)     (m)       (ug/m3)     (ppm)    "
3670 NLI=NLI+6
3680 FOR J = 1 TO 6
3690 PRINT #1, "------------------------------------------------------------":NLI=NLI+1
3700 FOR I = 1 TO NWS
3710 IF A(I,J) <> 1 GOTO 3740
3720 PRINT #1, USING FT$;J;V(I);HA(I,J);DISTD(I,J);CONCD(I,J)*TRAT;CONCD(I,J)*.0245/MWC*TRAT
3730 NLI=NLI+1:IF NLI>19 THEN GOSUB 4350
3740 NEXT I
3750 NEXT J
3760 GOSUB 4350
3770 PRINT #1, CHR$(12)
3780 PRINT #1, " Concentrations at Specific Receptor Distances"
3790 PRINT #1, "                                                    "
3800 PRINT #1, "Stability  Wind Distance Concentration              "
3810 PRINT #1, "  Class    Speed                                    "
3820 PRINT #1, "          (m/sec)    (m)       (ug/m3)       (ppm)        "
3830 NLI=6
3840 FOR J = 1 TO 6
```

```
3850 PRINT #1, "-------------------------------------------------":NLI=NLI+1
3851 ' Calculation of post-touchdown concentrations
3860 FOR K = 1 TO ISD
3870 PRINT #1, " ":NLI=NLI+1
3880 FOR I = 1 TO NWS
3890 IF A(I,J) <> 1 GOTO 4010
3910 LET DIFF = DIST(K) - DISTD(I,J)
3920 IF DIFF < 0! THEN GOTO 4010
3930 IF DISTF(I,J) < DISTD(I,J) THEN DISTF(I,J) = DISTD(I,J)
3940 IF DIST(K) < DISTF(I,J) THEN GOTO 3980
3950 LET CONC(I,J)=CONCD(I,J)*((DISTF(I,J)/DISTD(I,J))^(-.65))
3960 CONC(I,J)=CONC(I,J)*((DIST(K)/DISTF(I,J))^(-1.7))
3970 GOTO 3990
3980 LET CONC(I,J)=CONCD(I,J)*((DIST(K)/DISTD(I,J))^(-.65))
3990 PRINT #1, USING FT1$;J;V(I);DIST(K);CONC(I,J)*TRAT;CONC(I,J)*.0245/MWC*TRAT
4000 NLI=NLI+1:IF NLI>19 THEN GOSUB 4350
4010 NEXT I
4020 NEXT K
4030 NEXT J
4040 ICALC=1
4050 GOTO 4070
4060 PRINT #1, "":PRINT #1, "Treat as neutrally-buoyant for all stabilities and wind speeds"
4070 CLOSE#1:IF IPR=1 GOTO 4100
4080 INPUT "Would you like a printed output (yes=1, no=0)";ICOP1
4090 IF ICOP1=1 THEN IPR=I:GOTO 1870
4100 PRINT "Would you like to save your data to a disk file?"
4110 INPUT "(1=yes, 0=no) -- ",ISAV
4120 IF ISAV=0 THEN GOTO 4340
4130 INPUT "FILENAME";FIL$
4140 OPEN "O", #2, FIL$
4150 PRINT #2,TS
4160 PRINT #2,QC
4170 PRINT #2,EXITV
4180 PRINT #2,D
4190 PRINT #2,TO
4200 PRINT #2,HS
4210 PRINT #2,VOL
4220 PRINT #2,MW
4230 PRINT #2,MO
4240 PRINT #2,MWC
4241 PRINT #2,TDUR
4242 PRINT #2,TAV
4243 PRINT #2,PR
4250 PRINT #2,NWS
4260 FOR J=1 TO NWS:PRINT#2,V(J);:NEXT J:PRINT #2,""
4270 PRINT#2, ISD:FOR J=1 TO ISD:PRINT#2,DIST(J);:NEXT J:PRINT#2,""
4280 FOR J=1 TO 6:PRINT#2,TA(J);:NEXT J:PRINT#2,""
4290 PRINT #2,IWSP
4310 CLOSE#2:GOTO 4340
4320 INPUT "Would you like to save these data to a file anyway? (y or n) -- ",ANS$
4330 IF ANS$ = "y" OR ANS$ = "Y" THEN GOTO 4130
4340 INPUT "Another RVD run? (y or n) -- ",ANS$
4341 IF ANS$ = "y" OR ANS$ = "Y" THEN COLOR 3,1:CLS:IPR=0:ICALC=0:GOTO 800
4342 SYSTEM
4350 IF IPR=1 THEN RETURN
4360 PRINT "":PRINT "":PRINT "
4370 A$=INKEY$:IF A$="" THEN 4370                    Press any key to continue"
4380 NLI=0:CLS:RETURN
```